A Survey of Stored Product Insects in Hawaii[1]

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Although stored product insects have been recorded in Hawaii since 1877, no methodical survey had been conducted. The aim of the study reported here was to determine the occurrence, distribution, frequency, and economic importance of stored product insects in Hawaii.

Previous records of stored product insects in Hawaii are shown in Table 1. Bridwell (1918) considered that problems with stored product insects were of sufficient importance to warrant full time attention. The committee on common names of economic insects in Hawaii listed the following eight stored product species in 1921; (Anon. 1921) cadelle, *Tenebroides mauritanicus* (Linnaeus); drugstore beetle, *Stegobium paniceum* (Linnaeus) (listed as *Sitodrepa panicea* (Linnaeus)); driedfruit beetle, *Carpophilus hemipterus* (Linnaeus); granary weevil, *Sitophilus granarius* (Linnaeus) (as *Sitophila oryzae* (Linnaeus)); red flour beetle, *Tribolim castaneum* (Herbst) (as rusty flour beetle, *Tribolium ferrugineum* (Fabricius)); wardrobe beetle, *Attagenus fasciatus* (Thunberg) (as *Attagenus gloriosae* (Fabricius)); tobacco moth, *Ephestia elutella* (Hübner) (as cereal moth); Mediterranean flour moth, *Anagasta kuehniella* (Zeller) (as *Ephestia kuhniella* Zeller).

MATERIALS AND METHODS

The survey area included the islands of Oahu, Kauai, Hawaii, and Maui. Oahu, and particularly Honolulu as the center of commerce and highest concentration of people, was surveyed more intensively than the other places. The premises surveyed were flour and feed processing plants, feed stores, livestock ranches, riding stables, food warehouses, supermarket storage areas, and containers. Products examined included animal feeds and feed components such as bran, fishmeal and cottonseed meal; whole cereal grains such as wheat, oats, barley and corn; pet foods; processed cereal products such as flour, breakfast foods, prepared mixes, pasta products, polished rice; oatmeal products; cookies and biscuits; peanuts; cacao products; coconut; confections; nuts; dried fuits; seeds; and spices. Residences were not covered in the survey, but data on insects found in household products submitted by homeowners, tenants, and pest control operators were included.

Collections from light traps (Fig. 8) operated at 30 locations on Oahu were examined periodically for stored product insects at weekly or biweekly intervals from July 15 to December 31, 1976, and at monthly intervals thereafter until March 1977. Four of these traps were placed in or beside a feed mill, four were in locations

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TABLE 1. *Published reports of some stored product insects in Hawaii, 1877-1975*

Species	*Product*	*Locality*	*Author and Year Reported*
Pyralis manihotalis Guenee			Butler 1877[a]
Cadra cautella (Walker)	several stored		Butler 1877[a]
(as *Ephestia cautella*)	food products		
Plodia interpunctella (Hübner)	several stored food products		Butler 1879
Ephestiodes gilvescentella Ragonot		Molokai	Meyrick 1899[a]
Attagenus fasciatus (Thunberg)	houses	Honolulu	Blackburn and Sharp 1885
(as *Attagenus plebeuis* Sharp)			
Stegobium paniceum (Linnaeus)	in decaying timber	Honolulu	Blackburn and Sharp 1885
(as *Anobium paniceus* (L.))			
Lasioderma serricorne (Fabricius)	cigars	Honolulu	Blackburn and Sharp 1885
(as *Ptinus serricornis*)			
Gnathocerus cornutus (Fabricius)	flour	Honolulu	Blackburn and Sharp 1885
(as *Trogosita cornuta*)			
Tribolium castaneum (Herbst)	flour	Honolulu	Blackburn and Sharp 1885
Alphitobius diaperinus (Panzer)	flour and under stones	Maui and Oahu	Blackburn and Sharp 1885
(as *Tenebrio diaperinus*)			
Sitophilus oryzae (Linnaeus)	flour, sugar, and other edibles	Honolulu	Blackburn and Sharp 1885
(as *Curculio oryzae*)			
Sitotroga cerealella (Olivier)	stored corn	Maui	Swezey 1912[a]
Ephestia elutella (Hübner)	various cereal products and dried fruits	Honolulu	Swezey 1912[b]
Corcyra cephalonica (Stainton)	cracked wheat	Honolulu	Swezey 1912c[b]
Anagasta kūehniella (Zeller)		Honolulu	Swezey 1913
Tenebroides nanus (Melsheimer)	household	Honolulu	Swezey 1915
Tenebroides mauritanicus (Linnaeus)	blotting paper	Honolulu	Illingworth 1916
Gnathocerus maxillosus (Fabricius)		Honolulu	Fullaway 1922[c]
Lyctus brunneus (Stephens)			Scott 1925[d]
(as *Lyctus brunneas* [Stephens])			
Palorus ratzeburgi (Wissmann)	woodpile	Honolulu	Swezey 1936

Typhaea stercorea (Linnaeus)	dead vegetation and grain or grain products		Zimmerman 1939[e]
Rhyzopertha dominica (Fabricius)			Zimmerman 1941[f]
Carpophilus hemipterus (Linnaeus)		Kauai	Krauss 1944[g]
Oryzaephilus surinamensis (Linnaeus)		Kauai	Krauss 1944[g]
Tribolium castaneum (Herbst) (as *Tribolium ferrugineum*)		Kauai	Krauss 1944[g]
Sitophilus granarius (Linnaeus)	grain and feed warehouse	Honolulu	Krauss 1944[h]
Doliema plana (Fabricius)	light trap	Oahu	Zimmerman 1949
Tribolium confusum Jacquelin du Val	taro flour—skim milk	Honolulu	Holdaway 1947
Tenebrio molitor Linnaeus	woolen material	Oahu	Suehiro 1962[i]
Dermestes carnivorus Fabricius		Honolulu	Sadoyama 1966
Trogoderma inclusum LeConte	feed store	Honolulu	Olson *et. al.* 1970[j]
Oryzaephilus mercator (Fauvel)			Tsuda 1975[k]

[a]Found in Hawaii by Rev. T. Blackburn. Cited in Zimmerman (1958) Insects of Hawaii 8: 1-45.
[b]Not recorded in U.S.A. Found breeding in feed warehouse in Honolulu by Kotinsky in 1908.
[c]Reported having been collected in 1906.
[d]Reported having been collected in 1910.
[e]Found by Blackburn before 1885.
[f]Collected by Blackburn; listed from Oahu by Perkins (1910) (Fauna Hawaiiensis 3:643).
[g]Apparently new records for Kauai.
[h]Reported having apparently been seldom found in the Hawaiian Islands.
[i]Second specimen reported; the first had been collected by Perkins nearly 70 years earlier.
[j]Found in trap during survey for *Trogoderma granarium* Everts.
[k]Previously unrecorded, but probably present earlier and identified as *O. surinamensis*.

within two miles of feed mills, and 22 were located farther away from feed mills. Food-baited plastic traps (Pinniger 1975) (Fig. 8) each containing 25g wheat, 25g raw peanuts, 15g carob, and 15g dry dog food were placed in feed stores, food warehouses and supermarket storage areas for periods of three to nine days and then sifted to recover any insects present.

The number of species associated with stored products and the frequency of their occurrence were recorded. No quantitative assessments of the species found in samples and traps in different premises were made, but note was taken of extremely heavy infestations of any particular species. Fungus-feeding insects, parasites of stored product insects, and species other than stored product insects were also recorded. Figures on economic losses due to stored product insects were cited.

Visual examinations were made, and samples taken, of the contents of sacks and bags, dead stock under and around machinery, cracks and crevices in floors and walls, points of contact between piled bags and cartons, seams and creases of bags, burlap sacking, shelves, window ledges and other surfaces where dust accumulates, bases of shelf posts and pillars, under pallets, rat bait stations, and floor debris. Samples from premises and the contents of food-baited traps were sifted, and the insect species found therein were counted and recorded. Family or generic names were used where genera or species could not be ascertained, or where the habits or hosts were not known.

Results

Fifty-four species of beetles and 11 species of moths were found associated with stored products in Hawaii (Table 2). Most of these are shown in figures 1-6. Fourteen species of beetles occurred frequently; namely, *Alphitobius diaperinus* (Panzer), *Attagenus fasciatus, Carpophilus dimidiatus* (Fabricius), *Cryptolestes ferrugineus* (Stephens), *Cryptolestes pusillus* (Schönherr), *Dermestes maculatus* DeGeer, *Lasioderma serricorne* (Fabricius), *Oryzaephilus mercator* (Fauvel), *Rhyzopertha dominica* (Fabricius), *Sitophilus oryzae, Stegobium paniceum, Tribolium castaneum, Trogoderma anthrenoides* (Sharp), and *Typhaea stercorea* (Linnaeus). The most frequently occurring moths were *Cadra cautella* (Walker) and *Plodia interpunctella* (Hübner). Nine insect species are listed only by family (Table 2) where the genus was unknown or where no information was available about food habits. The most commonly encountered psocid was *Liposcelis* sp. *Typhaea stercorea* is a fungus-feeding insect but will also feed upon stored products. Mites were encountered frequently but not recorded. *Thorictodes heydeni* Reitter, mentioned by Beal (1961) from Micronesia, is apparently a new record for Hawaii. Several other species were encountered during the survey (Table 3). Some of these were parasites or predators of stored product insects. Others were found in feed samples, moldy feed, or light traps.

Seven species occurred frequently and consistently in the four feed mills examined (Table 4). Based on the number of times that each species was recorded, the most frequent were *Tribolium castaneum* and *Rhyzopertha dominica*. Six species were predominant in feed stores and four in ranches and riding stables. *T. castaneum* and *Sitophilus oryzae* occurred in 86% and 78%, respectively, of feed stores, and in 100% and 75%, respectively, of ranches.

Oryzaephilus mercator, the most frequent species in warehouses and supermarkets, was found in 79% of these premises (Table 4). The next most frequent species were *Lasioderma serricorne* and *T. castaneum* which occurred in 61% and 51% of

TABLE 2. *Insects found during 1976 - 1977 stored product pest survey.*

Common name	Scientific name	Number of times recorded during survey
Bean weevil	*Acanthoscelides obtectus* (Say)	2
	Aethriostoma undulata Motschusky	4
Foreign grain beetle	*Ahasverus advena* (Waltl)	5
Lesser mealworm	*Alphitobius diaperinus* (Panzer)	21
	Anthrenus oceanicus Fauvel	3
	Anthrenus sp.	1
Coffee bean weevil	*Araecerus fasciculatus* (De Geer)	2
Wardrobe beetle[f]	*Attagenus fasciatus* (Thunberg)	27
	Bruchidae[a]	11
Almond moth	*Cadra cautella* (Walker)	32
	Cadra sp.	2
Chinese bean weevil	*Callosobruchus chinensis* (Linnaeus)	1
Corn sap beetle	*Carpophilus dimidiatus* (Fabricius)[b]	14
Dried fruit beetle	*Carpophilus hemipterus* (Linnaeus)[c]	5
	Carpophilus sp.	7
	Cartodere constricta (Gyllenhal)[d]	1
	Coelopalorus foveicollis (Blair)	9
Rice moth	*Corcyra cephalonica* (Stainton)	4
Rusty grain beetle	*Cryptolestes ferrugineus* (Stephens)	11
Flat grain beetle	*Cryptolestes pusillus* (Schönherr)	16
	Cryptophilus integer (Heer)[d]	5
	Cucujidae[a]	4
Black larder beetle	*Dermestes ater* De Geer	2
	Dermestes carnivorus Fabricius	1
Hide beetle	*Dermestes maculatus* De Geer	4
	Dermestes sp.	3
	Dermestidae[a]	4
	Doliema plana (Fabricius)	3
	Doliema sp.	1
	Ephestiodes gilvescentella Ragonot	4
	Gibbium psylloides (Czemp)	2
Broadhorned flour beetle	*Gnathocerus cornutus* (Fabricius)	10
Slenderhorned flour beetle	*Gnathocerus maxillosus* (Fabricius)	2
Cigarette beetle	*Lasioderma serricorne* (Fabricius)	61
Longheaded flour beetle	*Latheticus oryzae* Waterhouse	4
	Lyctidae[a]	10
	Mycetophagidae[a,d]	4
Redlegged ham beetle	*Necrobia rufipes* (De Geer)	3
	Nitidulidae[a]	10
Merchant grain beetle	*Oryzaephilus mercator* (Fauvel)	50
Sawtoothed grain beetle	*Oryzaephilus surinamensis* (Linnaeus)	6
Smalleyed flour beetle	*Palorus ratzeburgi* (Wissmann)	2
Depressed flour beetle	*Palorus subdepressus* (Wollaston)	5
Navel orangeworm	*Paramyelois transitella* (Walker)	1
	Phycitidae[a]	32
Indian meal moth	*Plodia interpunctella* (Hübner)	16
	Psocoptera[a]	22
	Pyralis manihotalis Guenee	1
Lesser grain borer	*Rhyzopertha dominica* (Fabricius)	41
	Silvanus bidentatus (Fabricius)	1
Granary weevil	*Sitophilus granarius* (Linnaeus)	1
Rice weevil	*Sitophilus oryzae* (Linnaeus)	40
Angoumois grain moth	*Sitotroga cerealella* (Olivier)	6
Drugstore beetle	*Stegobium paniceum* (Linnaeus)	24
Cadelle	*Tenebroides mauritanicus* (Linnaeus)	5

TABLE 2 (Continued)

Common name	Scientific name	Number of times recorded during survey
	Tenebroides nanus (Melsheimer)	4
Casemaking clothes moth	*Tinea pellionella* (Linnaeus)	1
	Tineidae[a]	3
	Thorictodes heydeni Reitter[e]	1
Red flour beetle	*Tribolium castaneum* (Herbst)	84
Confused flour beetle	*Tribolium confusum* Jacquelin du Val	2
	Trogoderma anthrenoides (Sharp)	27
Warehouse beetle	*Trogoderma variabile* (Ballion)	2
	Trogoderma sp.	12
Hairy fungus beetle	*Typhaea stercorea* (Linnaeus)	53
	Urophorus humeralis (Fabricius)[b]	2

[a] Listed by family or order when genus is unknown or no information is available on hosts or habits.
[b] Listed as stored product insect in Farmers' Bulletin No. 1260, USDA, 1965.
[c] Listed as stored product insect by Hinton and Corbet, British Museum (Natural History) Economic Series, No. 15, 1972.
[d] Fungus feeders.
[e] First record for Hawaii.
[f] Common name approved by Committee on Common Names, Hawaiian Entomological Society.

these premises, respectively. The most frequently occurring species in containers were *T. castaneum* and *Trogoderma* spp.; and in residences, *L. serricorne* and *T. castaneum*. *L. serricorne* was found also in cigarettes and chocolate drink mix from vending machines. The cigarettes were badly punctured. The presence of all stages in the chocolate drink mix indicated a breeding population.

The highest number of stored product species was found in feed mills (Table 5). Every feed mill, feed store, livestock ranch, riding stable, warehouse and supermarket examined was infested with one or more species. The number of species listed in Table 5 for each kind of premise represents only those identified to species. Others were identified only to genus if the species was unknown. Still others were identified only to family if the specimens were too damaged or too immature to permit more precise identification. A few samples were identified only to order; for example, as "Lepidoptera," if webbing indicating the presence of moth larvae, but no insects were present. Because samples from residences were from premises known, or suspected to be infested, these do not represent random selections.

Of 18 food-baited traps placed in six infested feed and pet food stores, 83% contained from one to eight species of insects (Table 6). Thirteen species were found, the most frequent being *Oryzaephilus mercator* and *Sitophilus oryzae*. Of 64 similar traps placed in 18 food warehouses and supermarket storage areas, 60 were recovered, of which 77% contained from one to four species (Table 6). Eleven species were found, the most frequent being *L. serricorne, O. mercator,* and psocids. Miscellaneous species occasionally found in the traps included the bigheaded ant, *Pheidole megacephala* (Fabricius); predaceous bugs (Anthocoridae); and hymenopterous parasites (Pteromalidae). In warehouses, insects were sometimes found breeding in rat-bait stations; the two most frequent species being *Tribolium castaneum* and *O. mercator.* Some examples of the kinds of damage done by stored product insects, and their breeding sites are shown in Figs. 7 and 8.

TABLE 3. *Miscellaneous insects found during 1976-1977 stored product pest survey in Hawaii*

Genus or species	Family	Premises	Remarks
	Anobiidae	light trap	usually found under bark
Anoplolepis longipes (Jerdon)	Formicidae	feed warehouse	
	Anthicidae	light trap in feed mill	
	Anthocoridae	in baited plastic trap in feed store	predator
Blapstinus isistricus Casey	Tenebrionidae	feed mill	
Blapstinus dilatatus LeConte	Tenebrionidae	feed mill	
	Calliphoridae	fish plant	larvae in fish meal
	Carabidae	light trap	
	Curculionidae	livestock ranch	found in damp feed usually found boring in wood
	Cucujidae	light trap	
Dermestes sp.	Dermestidae	feed mill	soil scavenger
Dinoderus sp.	Bostrichidae	feed store	in oat feed
Euxestus erithicus (Chevrolat)	Colydiidae	light trap	usually found on rotting vegetation
Haptoncus sp.	Nitidulidae	light trap	
Hermetia illucens (Linnaeus)	Stratiomyidae	feed mill	larvae in moldy barley
Holoparamecus caularum (Aubé)	Lathridiidae	grain spillage in feed mill	usually found on decaying vegetation
	Lathridiidae	light trap	
Litargus balteatus LeConte	Mycetophagidae	light trap	

TABLE 3 (cont)

Genus or species	Family	Premises	Remarks
Microgramme ruficollis (Marsham)	Lathridiidae	feed mill	
Minthea reticulata Lesne	Lyctidae	warehouse	boring in bamboo chopsticks
Nauphoeta cinerea (Olivier)	Blattidae	feed mill	commonly found in feed debris
	Oecophoridae	feed bins on horse ranch	
Orphinus terminale (Sharp)	Dermestidae	apartment	
Orphinus sp.	Dermestidae	light trap in feed mill	
Oxydema fusiforme Wollaston	Curculionidae	livestock ranch	usually found in rotting vegetation or wood
Pheidole megacephala (Fabricius)	Formicidae	feed stores and baited traps	
	Pteromalidae	warehouses, feed mills	parasite
Pycnoscelus surinamensis (Linnaeus)	Blattidae	under damp burlap sacks and damp grain in feed mills	
	Reduviidae	livestock ranch	predator
Scenopinus sp.	Scenopinidae	livestock ranch	predator
Stator pruininus (Horn)	Bruchidae	light traps	
	Staphylinidae	feed mill and light traps	
Xyleborus sp.	Scolytidae	grain spillage in feed mill	

Of 30 light traps at 30 different locations on Oahu, collections from 14 (47%) contained stored product insects. Thirty-three species of known or suspected stored product insects were represented. Eight traps were situated beside or within 2 miles of feed mills and these all caught up to 32 species of stored product insects. Twenty-two traps located at Kahua Ranch, Sand Island, Waipahu, Ewa, Kunia, Honolulu airport, and Hickam Air Force Base were not near feed mills. Six of these (27%) caught up to 10 stored product species. Two of the six each caught a single specimen of a stored product species on only one occasion. The most frequently collected species were as follows:

Species	*Number of trap locations*	*Number of times recorded*
Typhaea stercorea	12	41
Phycitidae	9	28
Stegobium paniceum	6	13
Attagenus fasciatus	6	10
Trogoderma anthrenoides	7	9
Tribolium castaneum	6	7
Rhyzopertha dominica	6	6

The phycitid moths were represented predominantly by *Plodia interpunctella, Cadra cautella,* and *Ephestiodes gilvescentella*. These species were frequently found in traps beside or within two miles of feed mills. Other undetermined phycitids were occasionally collected in light traps.

Economic losses.

Based on 1977 figures, the cost of disinfestation and preparation of a container for carrying consumer foods is 158 dollars. If one considers the number of containers that require this kind of maintenance, the total cost adds up to hundreds of thousands of dollars per year.

In a single warehouse in Hawaii the dollar loss of infested pet food that was destroyed in 1975 exceeded $3,500. This figure does not include the value of other discarded goods where insects may have been involved but were not specifically mentioned. In another warehouse, the cost of fumigating containers during a 13-month period ending January 1977 was more than $3,000. In 1977, 1300 bales of 5-lb bags of flour stored in a warehouse were fumigated, and then had to be destroyed because of heavy internal infestation by flour beetles. The manufacturer's value of the flour was $9,000, and the cost of fumigation and disposal was $500. In a similar situation, 400 cartons of infested pancake mix with a wholesale value of $3,300 was destroyed. The disposal costs added another $150.

One warehousing company spends annually up to $12,000 for service and materials pertinent to pest problems. In 1976, this company discarded food having a wholesale value of $20,000 because of contamination by insects, rodents, and birds. Vast quantities of rice, cereal foods for infants, milk powder, and similar food commodities in long-term storage must be fumigated frequently. Undoubtedly, these commodities suffer deterioration during these long periods, and in some cases are totally lost. For example, recently in the mainland U.S. and in foreign countries, approximately $1.5 million worth of cocoa beverage mix had to be destroyed because of infestation by *Trogoderma variabile*.

During the survey, countless discarded, infested packages of rice, pasta, cereal products, prepared mixes, spices, chocolate, dried fruits, nuts, confections, feeds,

TABLE 4. *Occurrence, number, percent and frequency of predominant stored product species in different kinds of premises.*

Premises		Species	Premises infested		Number of times recorded
Kind	Total number		Number	Percent	
Feed mills	4	*Alphitobius diaperinus*	4	100	9
		Attagenus fasciatus and *A.* sp.	3	75	9
		Rhyzopertha dominica	4	100	11
		Sitophilus oryzae	4	100	7
		Stegobium paniceum	3	75	7
		Tribolium castaneum	4	100	11
		Typhaea stercorea	3	75	6
Feed stores	14	*Attagenus fasciatus* and *A.* sp.	8	57	10
		Carpophilus dimidiatus	6	43	8
		Oryzaephilus mercator	6	43	8
		Rhyzopertha dominica	8	57	8
		Sitophilus oryzae	11	78	15
		Tribolium castaneum	12	86	14
Livestock ranches and riding stables	8	*Alphitobius diaperinus*	4	50	4
		Rhyzopertha dominica	5	63	6
		Sitophilus oryzae	6	75	7
		Tribolium castaneum	8	100	8
Warehouses and supermarkets	33	*Cadra cautella*	9	27	14
		Lasioderma serricorne	20	61	31
		Oryzaephilus mercator	26	79	34
		Plodia interpunctella	9	27	10
		Tribolium castaneum	17	51	27
Containers	34	*Rhyzopertha domlnica*	9	26	9
		Sitophilus oryzae	5	15	5
		Tribolium castaneum	14	41	14
		Trogoderma sp.	11	32	11
Residences	37	*Lasioderma serricorne*	18	49	18
		Oryzaephilus mercator	5	13	5
		Psocoptera	5	13	5
		Tribolium castaneum	8	22	8

seeds, and pet foods in various premises and from homes were observed. The value of these goods undoubtedly represents a substantial sum.

Discussion

This survey has shown that stored product insects are widespread in Hawaii and pose a serious problem to food and feed processors, shippers, warehousemen, retailers, and consumers. The species of beetles and moths found most frequently are among the world's most serious pests of raw and processed foods. Some of the species of moths, particularly *Plodia interpunctella,* probably occurred more frequently than the data indicate (Table 2). The adults were more active at night than during daylight hours when premises were examined. Thus, light infestations could have escaped detection. The largest number and variety of stored product insects were found in feed mills and premises used for storage and sale of livestock feeds and pet foods. This finding reflects a lesser application of sanitation measures in feeds intended for livestock and other animals than in human foods. Many of the components used in the formulation and manufacture of animal feeds do not receive the same care and attention as those intended for human consumption. Bran, for example, is frequently heavily infested because, during the flour milling process, insects are carried along with the coarser particles to the feed end of the mill where much of the bran is bagged for feed (Loschiavo, 1952).

Because *Tribolium castaneum* was found in every kind of premises covered in the survey, it is considered to be the most common and widespread stored product insect in Hawaii. This species was the most predominant one in premises where feeds were manufactured, stored, or sold. A closely related species, *T. confusum,* was recorded only twice from Hawaii, once from a container and a second time from feed at a riding stable. Evidently, environmental conditions in Hawaii are more suited to the development and multiplication of *T. castaneum* than *T. confusum*. Although both of these flour beetle species are cosmopolitan, in continental North America *T. confusum* is more commonly found in northern latitudes and *T. castaneum* in the relatively warmer southern areas. Although *T. castaneum* was the species most commonly encountered during the survey, it was caught in light traps less often than some other stored product species. Perhaps *T. castaneum* is not strongly attracted to light.

Anagasta kuehniella and *Tenebrio molitor,* although common pests of stored products in temperate regions, were not found during the survey. The former is not established in Hawaii (Zimmerman, 1958) and the latter occurs only rarely (Suehiro, 1962).

Sitophilus oryzae was the second most predominant species in feed premises. This is not surprising in view of its requirement to feed, oviposit, and spend all stages of its development, except the adult stage, inside the kernel of whole grain. Because large quantities of whole grains are stored in feed mills for use in the manufacture of feeds, suitable food for *S. oryzae* is plentiful in Hawaii. The closely related *S. granarius* was recorded only once during the survey, from a feed store on Kauai. This species, like *T. confusum,* prefers a temperate climate, whereas *S. oryzae* is found more frequently in the warmer parts of the world where it causes great damage to cereal grains. *Rhyzopertha dominica* was the third most commonly occurring pest in feed premises. It thrives in warm regions where it causes serious damage to grains both in the larval and adult stages. Because it can readily penetrate cloth, paper, cardboard or plastic, it causes considerable damage to bagged and packaged food commodities. The presence of dermestid beetles such

TABLE 5. *Kind, number, and infestation of various premises by stored products insects.*

Kind of premises	*Number examined*	*Number of visits*	*Number infested*	*Percent infested*	*Species*	
					Number	*Range*
Feed Mills	4	13	4	100	34	5-18
Feed stores	14	21	14	100	26	2-12
Livestock ranches and riding stables	8	9	8	100	24	5-12
Warehouses and supermarkets	33	56	33	100	24	1-9
Containers	34[a]	—	27	79	17	1-5
Residences	37[b]	—	36	97	17	1-3

[a]15 containers were known to be infested. Of the 19 that were randomly selected, 12 (63%) were infested.
[b]Based on samples submitted by residents and pest control operators. The survey did not include a random sampling of homes and apartments.

TABLE 6. *Number and percent of food-baited traps infested with stored product insects one week after placement in two kinds of premises, and number and range of species recovered.*

Kind of premises	*Number of premises*		*Number of traps*		*Traps with insects*		*Species*	
	With traps	*With insects*	*Placed*	*Recovered*	*Number*	*Percent*	*Number*	*Range*
Feed and pet food stores	6	6	18	18	15	83	13	1-8
Warehouses and supermarket storage areas	18	18	64	60	46	77	11	1-4

as *Attagenus, Trogoderma,* and *Dermestes* spp. in feed mills suggests a preference by these insects for the high protein components used in feed formulations; for example, fish meal, bran and yeast. *Alphitobius diaperinus* was found predominantly in feed mills and livestock ranches, and was frequently associated with damp moldy grain in spillages on the ground. It prefers grain and cereal products that are deteriorating (USDA, 1965). Toyama and Ikeda (1976) found this species and several dermestid species on chicken carcasses on poultry farms, and *A. diaperinus* under manure cones as well.

Whole grain feeds and feed components were not found in food warehouses or supermarkets, and consequently the species of insects that occurred most frequently in feed premises were of minor significance where consumer goods were stored. The predominance of *Oryzaephilus mercator* in food storage areas indicates its importance as a pest of processed cereals. In Canada and the mainland U.S.A., this species (in the past often misidentified as *O. surinamensis)* is a widespread, firmly established pest of processed cereal products (Loschiavo and Smith, 1970). It was found frequently in pet foods and sunflower seeds, which have a high fat or oil content. *O. mercator* frequently infests products high in oil content (Loschiavo and Smith, 1970) and is associated with oil seeds (Howe, 1956). *O. mercator* was first recognized as present in Hawaii by Tsuda (1975). The frequent occurrence of *Lasioderma serricorne* in warehouses, supermarkets and residences reflects this species' diverse feeding habits and widespread distribution (Strong and Okumura, 1958).

The data from residences are too few to permit conclusions on the distribution and frequency of stored product insects in homes and apartments. However, it is interesting to note that the three most common species in warehouses and supermarkets also occurred in residences.

The predominance in containers, of species usually found in feed premises indicates the dual function of containers as carriers of feeds and of consumer goods. In fact, samples from empty containers in which these species were found inevitably consisted of feed components. The use of containers for shipping feeds and consumer goods interchangably probably contributes to cross-infestation and spread of stored product insects.

The food-baited traps in feed premises, warehouses and supermarkets proved to be highly sensitive and reliable insect-detection devices. Specimens of *Sitophilus oryzae* and *Oryzaephilus mercator* adults, and *Trogoderma* sp. larvae were found in traps placed in a warehouse seed storage room maintained at 10°C (50°F). In another example, traps that were incubated for a few weeks after removal from an apparently uninfested storeroom yielded about 30 larvae of *Cadra cautella.* The success of these field tests suggests that these traps may be used as insect-monitoring devices wherever food products are stored, or as a means of determining the effectiveness of insecticidal treatments in industrial premises.

The high frequency of *Sitophilus oryzae* in food-baited traps in feed stores is consistent with this species' presence in large numbers in these premises. On the other hand, *Oryzaephilus mercator* was found more often than *Tribolium castaneum* in traps placed in feed stores despite *T. castaneum's* greater frequency of occurrence in feed stores. The predominance of *O. mercator* in traps placed in feed stores, food warehouses, or supermarket storage areas suggests that the bait mixture used was particularly suitable for this species. The relatively infrequent occurrence of *T. castaneum* in the food traps despite its widespread distribution suggests that different combinations of food components may be necessary to attract different species.

Obviously, the larger number of stored product species caught in light traps located in, beside, or within two miles of feed mills than in those farther away indicates the larger concentration of these species near their food sources. The common occurrence of stored product insects in light trap catches in Hawaii suggests that these species are more active at the higher temperatures of Hawaii than the lower ones which prevail during much of the year in more temperate regions. Relatively frequent flight activity in Hawaii probably contributes to the rapid spread of these insects. The results indicate that light traps are useful monitoring devices for stored product insects as well as for other species, at least in tropical areas.

The survey covered only a small fraction of premises where foods and feeds are processed, stored, or sold, and consequently the loss figures cited represent only a tiny fraction of the total losses. If we were to add to these losses the countless packages of partially used flour, cereals, pasta products, prepared mixes, spices, chocolate, dried fruits, nuts, candy bars, etc. that are found infested and are discarded, and the damage by insects to carpets, clothing, and furnishings, the figures would be far higher. Other sources of economic losses faced by the food industry are fines and penalties by government agencies charged with the responsibility to ensure the wholesomeness of consumer foods, litigation by consumers who allegedly suffer ill-effects from eating infested food, and insurance claims. In addition, there is a danger that people may suffer intestinal disorders, allergies, and other irritations from ingestion of, or exposure to insects (Okumura, 1972).

Summary and Conclusions

A survey to determine the occurrence, distribution, frequency, and economic importance of stored product insects in Hawaii disclosed 54 species of beetles and 11 species of moths which are actual or potential pests. Of these, 14 of the beetles and two of the moths occurred frequently, and are among the world's most important economic pests. These insects were found in feed and food processing plants, feed stores, livestock ranches, containers, food warehouses, supermarket storage areas, and residences. Food-baited plastic traps and light traps were used in addition to visual examination of samples from premises to determine the presence and distribution of these insects. The baited traps proved to be effective insect-detection devices in warehouses and feed stores where they were tested. More stored product species were recovered from light traps in, beside or within two miles of feed mills than from those farther away.

The survey showed that stored product insects are widespread in Hawaii and pose a serious economic problem. The warm climate is conducive to the rapid development, multiplication, and spread of insects. In an island economy it is necessary to store substantial food reserves, and the longer the storage period the greater is the probability of infestation. Consequently, food losses due to stored product insects are probably proportionally higher in Hawaii than in the temperate regions of the mainland.

The greater vulnerability of stored products to attack by insects in Hawaii and similar tropical areas requires that considerable attention be devoted to insect prevention and control. The best way to control these insects is by following sound sanitation programs which integrate good housekeeping and chemical control. Good housekeeping will reduce dependence on chemicals. If chemical control is necessary it will be more successful if insect populations have already been reduced through good housekeeping.

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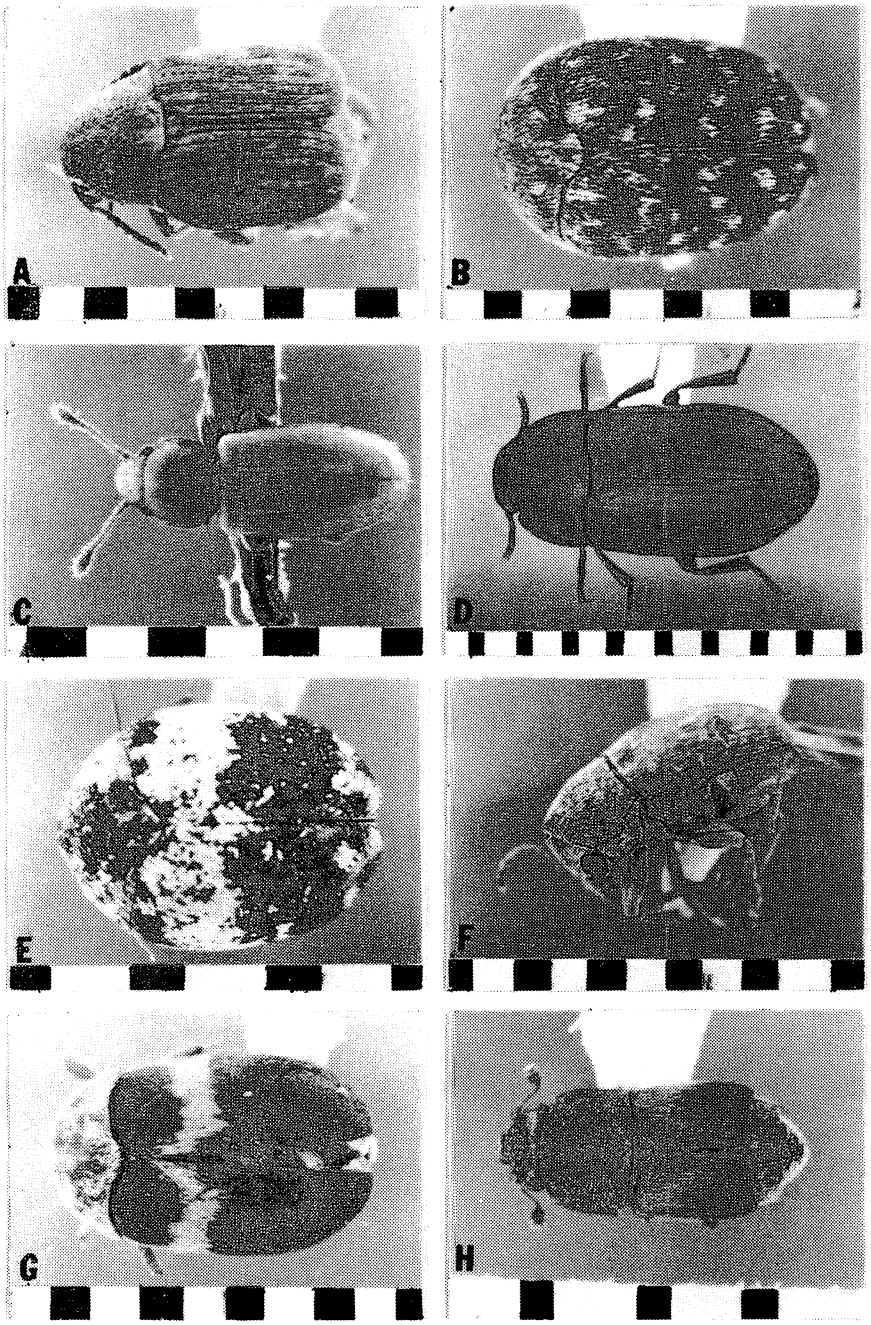

FIG. 1. Stored product insects in Hawaii: A, *Acanthoscelides obtectus*; B, *Aethriostma undulata*; C, *Ahasverus advena*; D, *Alphitobius diaperinus*; E, *Anthrenus oceanicus*; F, *Araecerus fasciculatus*; G, *Attagenus fasciatus*; H, *Carpophilus dimidiatus*. Scale in mm.

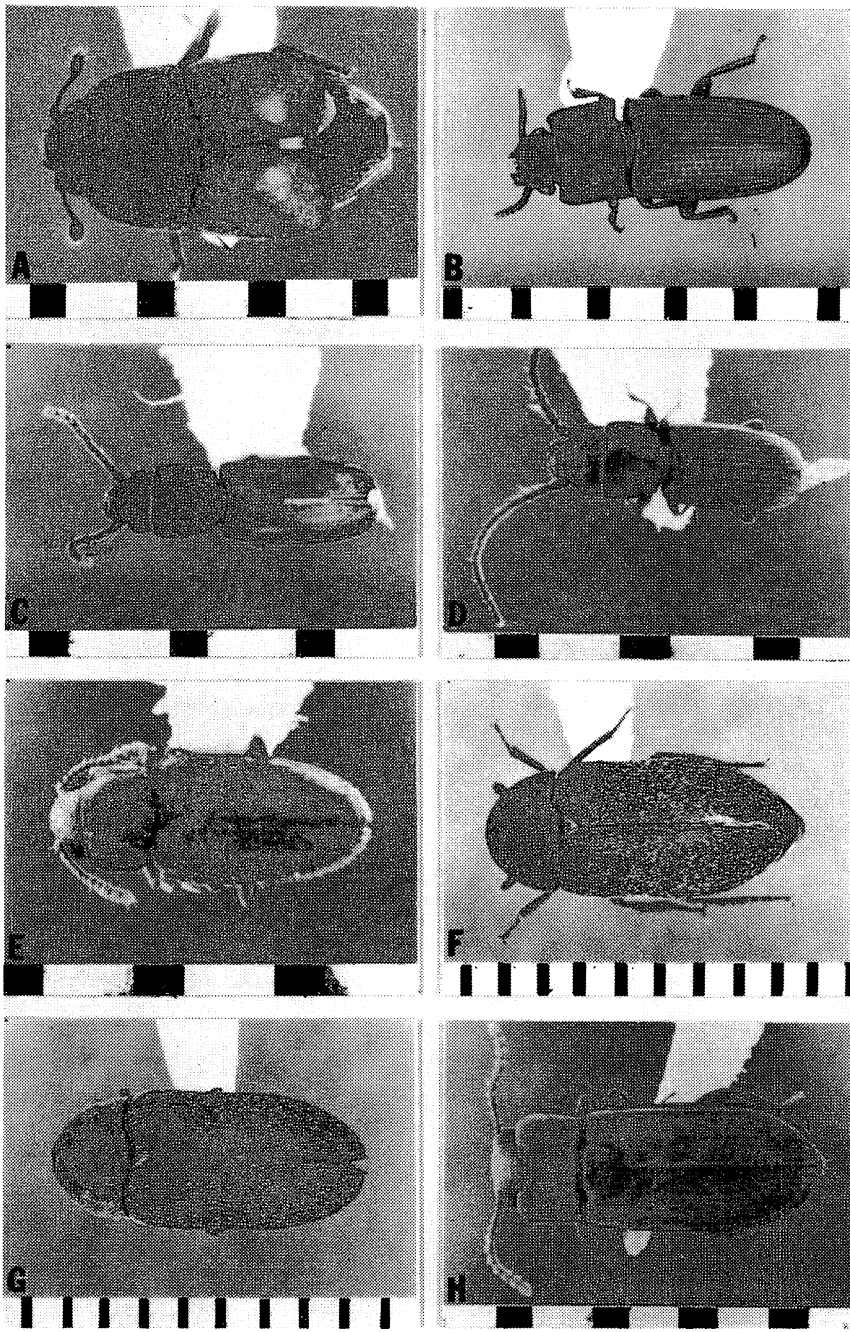

FIG 2. Stored product insects in Hawaii: A, *Carpophilus hemipterus*; B, *Coelopalorus foveicollis*; C, *Cryptolestes ferrugineus*; D, *Cyrptolestes pusillus*; E, *Cryptophilus integer*; F, *Dermestes carnivorus*; G, *Dermestes maculatus*; H, *Doliema plana*. Scale in mm.

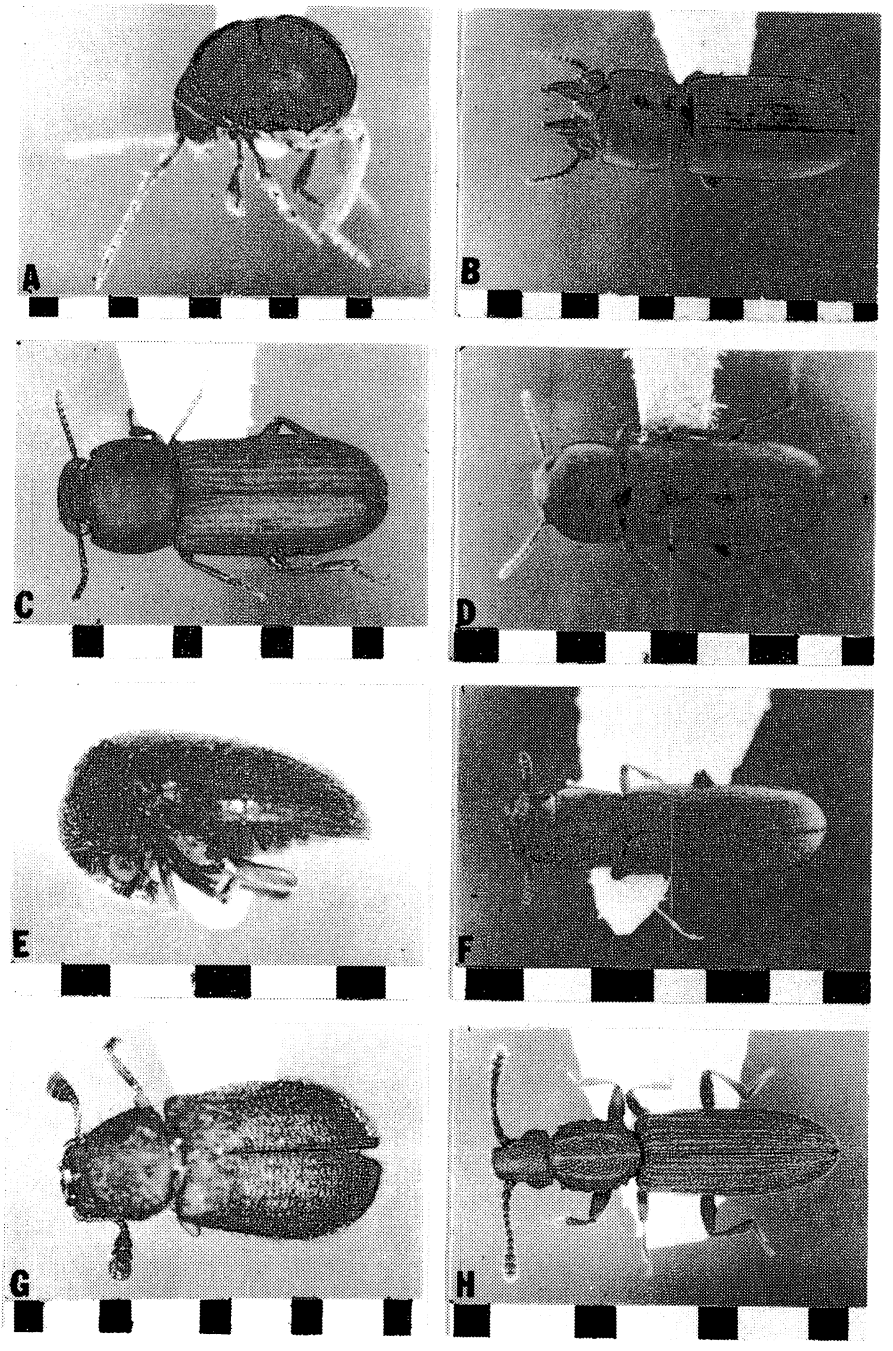

FIG 3. Stored product insects in Hawaii. A, *Gibbium psylloides*; B, *Gnathocerus cornutus* (male); C, *Gnathocerus cornutus* (female); D, *Gnathocerus maxillosus*; E, *Lasioderma serricorne*; F, *Latheticus oryzae*; G, *Necrobia rufipes*; H, *Oryzaephilus mercator*. Scale in mm.

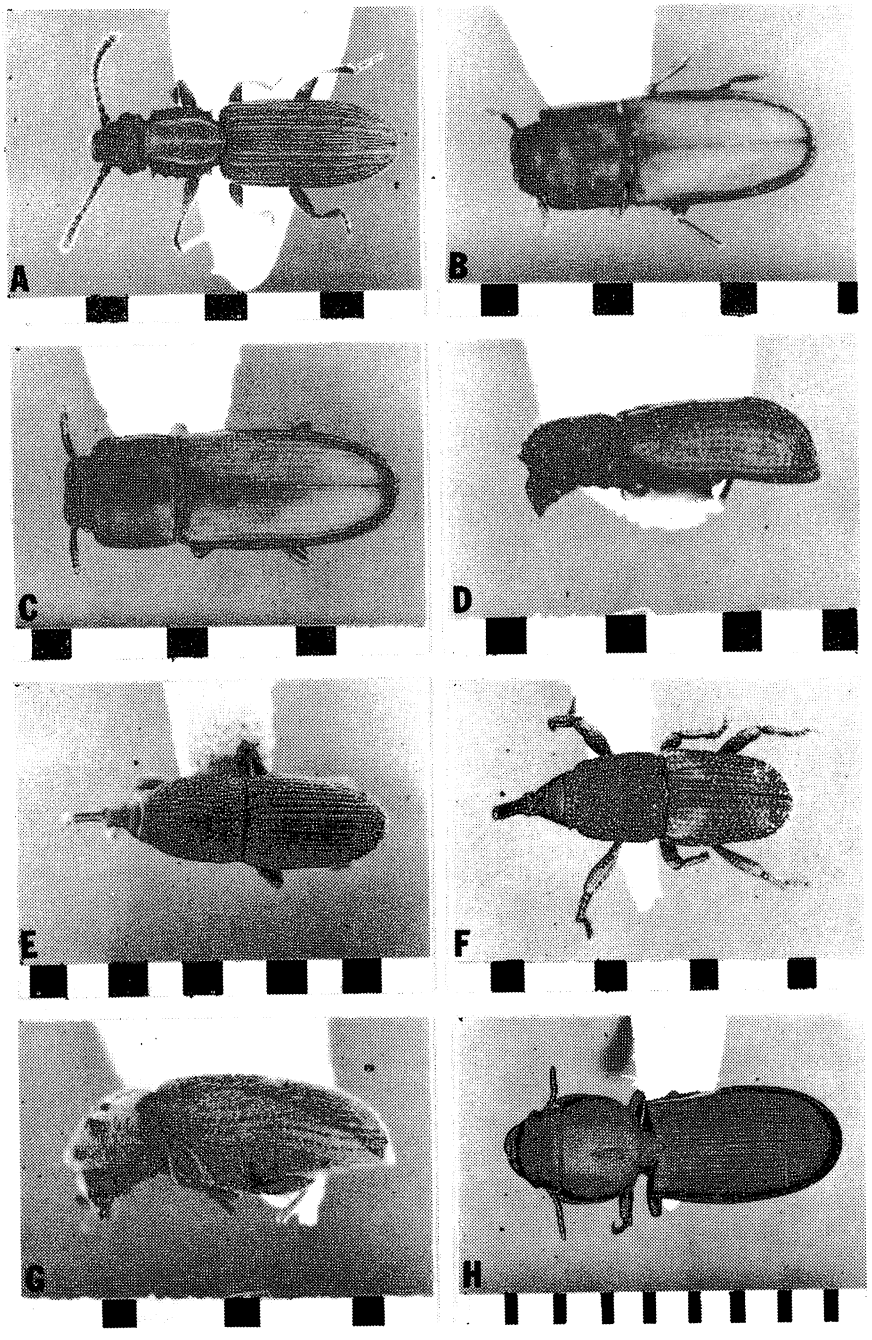

FIG 4. Stored product insects in Hawaii. A, *Oryzaephilus surinamensis*; B, *Palorus ratzeburgi*; C, *Palorus subdepressus*; D, *Rhyzopertha dominica*; E, *Sitophilus granarius*; F, *Sitophilus oryzae*; G, *Stegobium paniceum*; H, *Tenebroides mauritanicus*. Scale in mm.

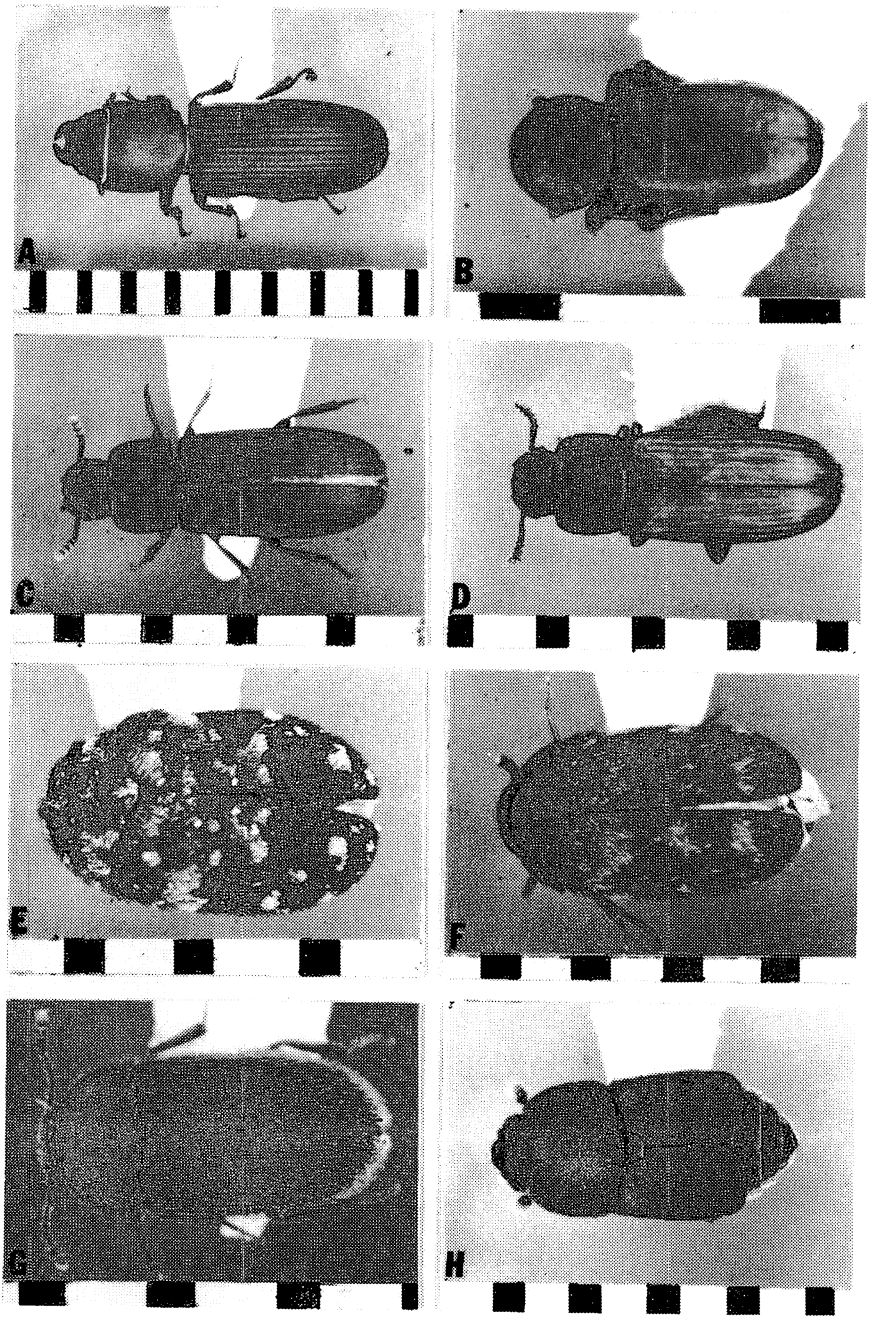

FIG. 5. Stored product insects in Hawaii: A, *Tenebroides nanus*; B, *Thorictodes heydeni*; C, *Tribolium castaneum*, D, *Tribolium confusum*; E, *Trogoderma anthrenoides*; F, *Trogoderma variabile*; G, *Typhaea stercoria;* H. *Urophorus humeralis*. Scale in mm.

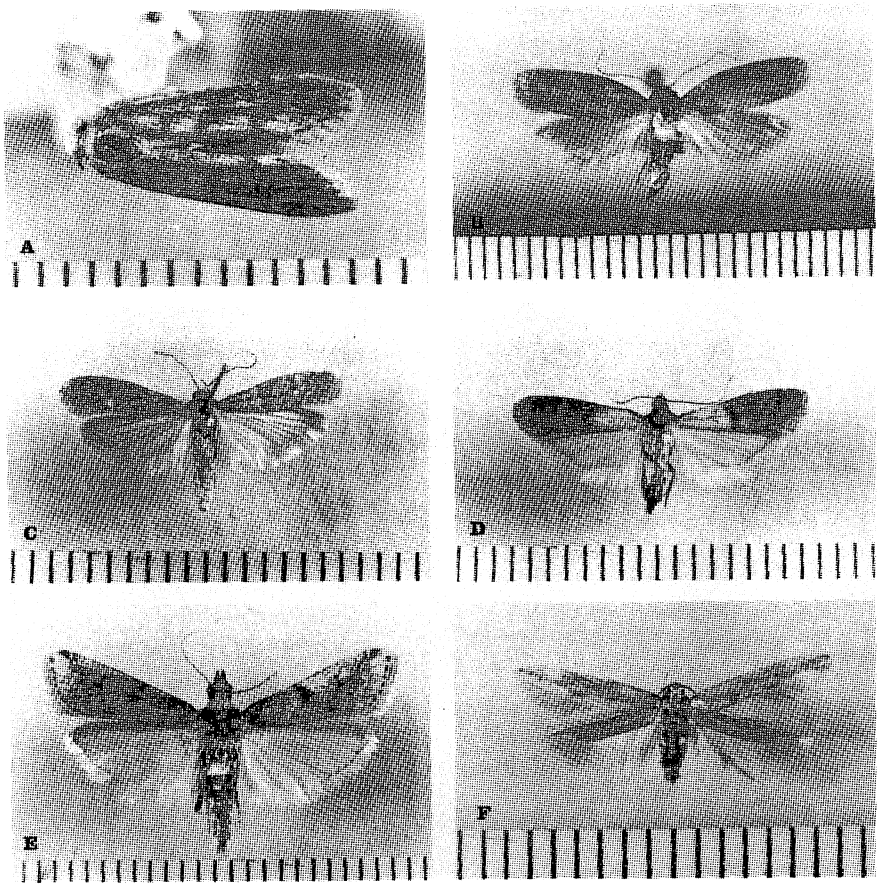

FIG 6. Stored product insects of Hawaii: A, *Corcyra cephalonica*, relaxed position; B, *Corcyra cephalonica*; C, *Cadra cautella*; D, *Plodia interpunctella*; E, *Paramyelois transitella*; F. *Sitotroga cerealella*. Scale in mm.

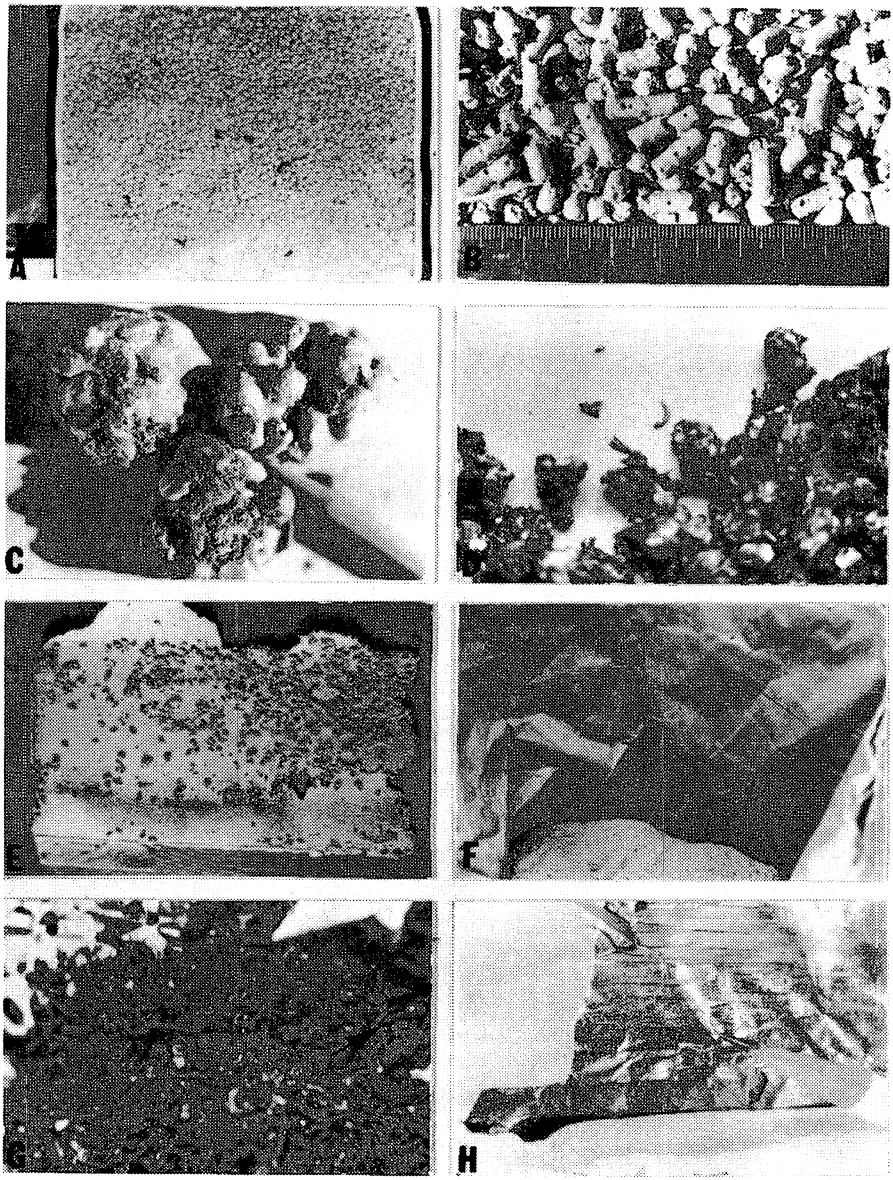

FIG 7. Damage by stored product insects: A, *Oryzaephilus mercator* and *Tribolium castaneum* inside package of sesame seeds; B, dog food pellets riddled with holes made by *Lasioderma serricorne* and *Oryzaephilus mercator*; C, chocolate nut candy covered with webbing and frass by *Plodia interpunctella*; D, candy-coated popcorn infested with *Plodia interpunctella*; E, inside surface of package of pizza mix covered with pupal cases of *Lasioderma serricorne*; F, bag of feed infested with *Tribolium castaneum*; G, tea and chocolate infested with *Lasioderma serricorne*; H, metallic tape from container. Note adult of *Tribolium castaneum* on adhesive side near pencil point.

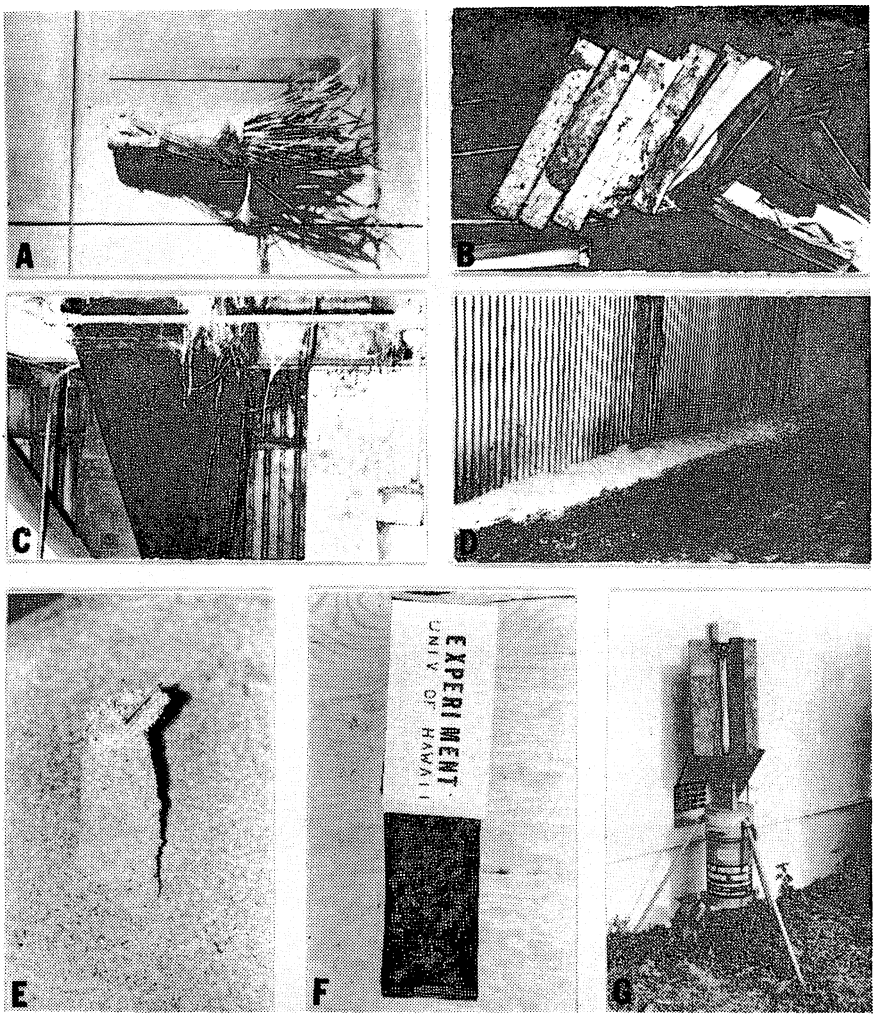

FIG. 8. Damage by stored product insects, breeding sites, and traps used in the survey. A, feather duster consumed by *Anthrenus* sp.; B, books damaged by several species; C, moth webbing hanging from ceiling in a feed mill; D, grain spillage from a feed mill storage shed; E, column of spoiling wheat standing in a pile stored in a shed. Note germinating kernels beside pencil; F, food-baited plastic trap; G, light trap.